Search for the Standard Model Higgs at Tevatron

Rocío Vilar Cortabitarte
for the CDF and D0 collaboration

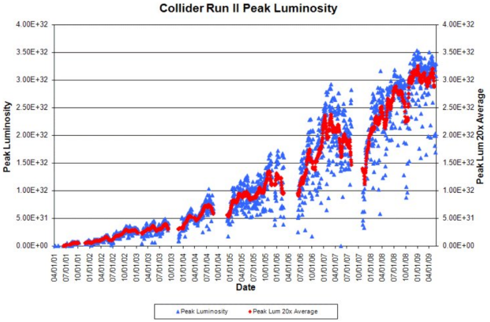
Instituto de Física de Cantabria - CSIC-UC

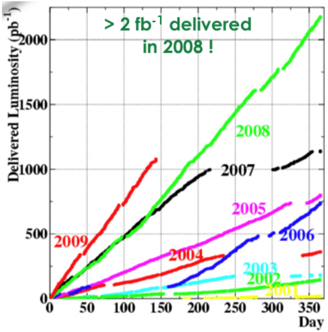
21-26th June 2009
XXIèmes Rencontres de Blois: Windows on the Universe

Tevatron Performance

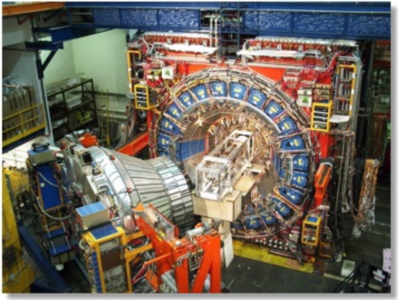
Highest-energy operational accelerator ($p\bar{p}$) $\Rightarrow \sqrt{s} = 1.96\,TeV$

performing very well!!
Typical initial inst. Luminosity: $\approx 3.3(3.5) \cdot 10^{32} cm^{-2} s^{-1}$
Integrated Luminosity/week (month): $\approx 75pb^{-1}/(260pb^{-1})$

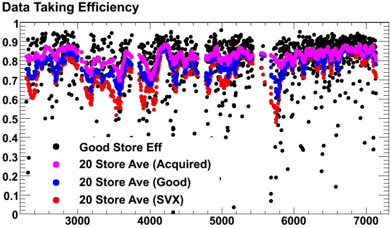


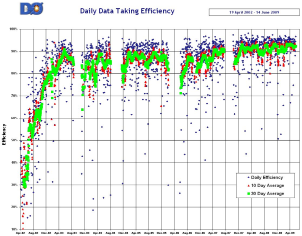


Detectors




D0


Data Taking Efficiency
Good Store Eff
20 Store Ave (Acquired)
20 Store Ave (Good)
20 Store Ave (SVX)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
3000
4000
5000
6000
7000

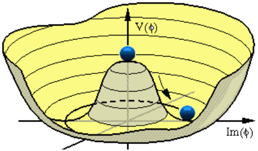

Daily Data Taking Efficiency
19 April 2002 - 14 June 2009
Efficiency
Daily Efficiency
10 Day Average
30 Day Average

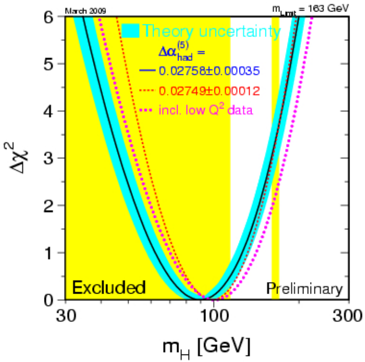
Standard Model Higgs Boson

- The SM has a broken symmetry: Particles have masses
- Within SM the responsible for the EWSB the Higgs mechanism → Higgs Boson
  - allows fermion masses through Yukawa couplings
- Higgs boson has not been observed yet but:
  - Lower bound from LEP limits: $M_H \geq 114.4$ GeV
  - Global EW Fit favors a low Higgs Mass:

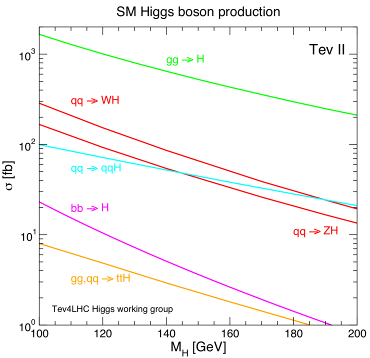
$$M_H = 90^{+34}_{-27} GeV$$

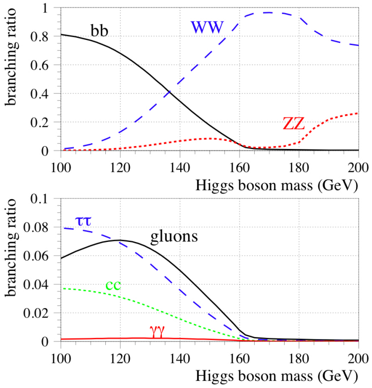
$M_H \leq 163(191) GeV$ (at 95% C.L)





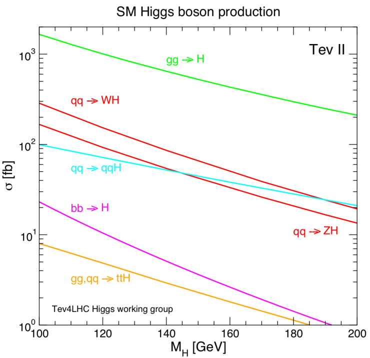
Production and Decay at Tevatron

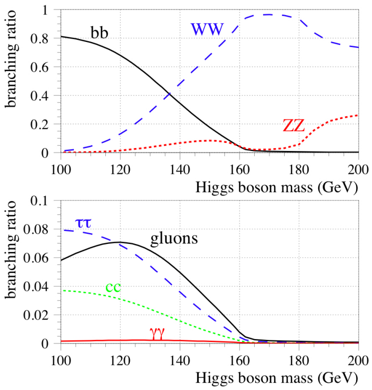




- Low Mass ($M_H \leq\sim 135\ GeV$)
  - $gg \rightarrow H$ production and $H \rightarrow b\bar{b}$ decay mode dominant but overwhelmed by QCD background
  - Use VH production
- High Mass ($M_H \geq\sim 135\ GeV$)
  - $gg \rightarrow H$ production mode and $H \rightarrow WW$ decay mode are dominant in this region
  - Use this channel

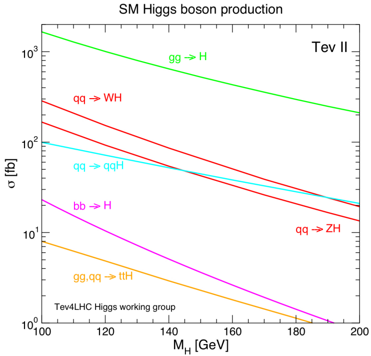
Production and Decay at Tevatron

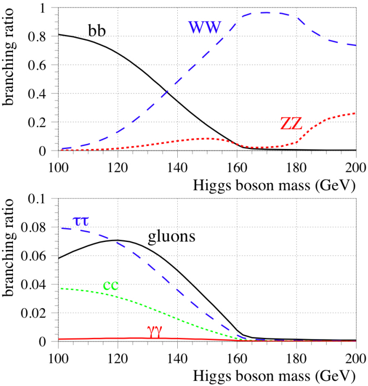




- Low Mass ($M_H \leq\sim 135\ GeV$)
  - $gg \rightarrow H$ production and $H \rightarrow b\bar{b}$ decay mode dominant but overwhelmed by QCD background
  - Use VH production
- High Mass ($M_H \geq\sim 135\ GeV$)
  - $gg \rightarrow H$ production mode and $H \rightarrow WW$ decay mode are dominant in this region
  - Use this channel

Production and Decay at Tevatron



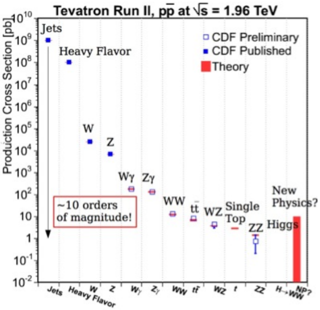


- Low Mass ($M_H \leq\sim 135\ GeV$)
  - $gg \rightarrow H$ production and $H \rightarrow b\bar{b}$ decay mode dominant but overwhelmed by QCD background
  - Use VH production
- High Mass ($M_H \geq\sim 135\ GeV$)
  - $gg \rightarrow H$ production mode and $H \rightarrow WW$ decay mode are dominant in this region
  - Use this channel

Experimental Challenges

Higgs signal is 10 orders of magnitude smaller than background

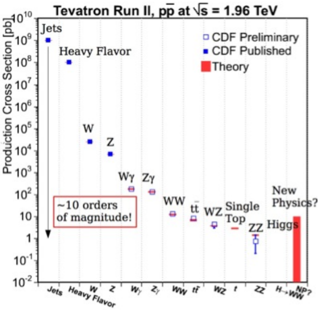
- Triggers: High P_T lepton (e μ), jet and Transverse Missing Energy ($\not\!\!E_T$), and dedicated τ triggers
- Lepton Id: Optimization using large samples of W/Z bosons
- Jet Energy resolution and Jet Identification algorithm:
  - B-jet identification (b-taggers): Secondary vertex reconstruction, Jet probability, Neural Network and Flavor separators



Experimental Challenges

Higgs signal is 10 orders of magnitude smaller than background

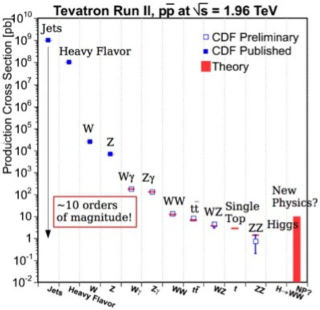
- Triggers: High P_T lepton (e μ), jet and Transverse Missing Energy ($\not\!\!E_T$), and dedicated τ triggers
- Lepton Id: Optimization using large samples of W/Z bosons
- Jet Energy resolution and Jet Identification algorithm:
  - B-jet identification (b-taggers): Secondary vertex reconstruction, Jet probability, Neural Network and Flavor separators

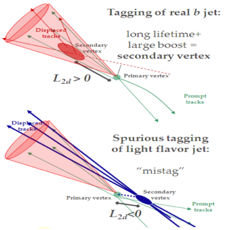


Experimental Challenges

Higgs signal is 10 orders of magnitude smaller than background

- Triggers: High P_T lepton (e μ), jet and Transverse Missing Energy ($\not{E}_T$), and dedicated τ triggers
- Lepton Id: Optimization using large samples of W/Z bosons
- Jet Energy resolution and Jet Identification algorithm:
  - B-jet identification (b-taggers): Secondary vertex reconstruction, Jet probability, Neural Network and Flavor separators





Experimental Challenges

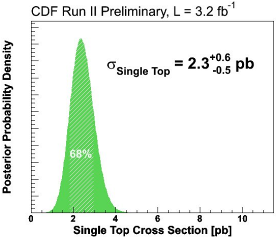
Higgs signal is 10 orders of magnitude smaller than background

- Understanding backgrounds
  - SM creates a large variety of background
    - W/Z+jets, dibosons, top, etc. modeled from MC
    - Mistags, QCD modeled from data
  - Critical issues for Higgs
    - Control regions to check bkg. prediction
    - Constrain bkg. prediction $\longrightarrow$ precise measurements of SM cross section
    - Testing tools and techniques: Measurements of bkg. processes such as WW, WZ, single-top, etc.
- Advanced analysis techniques (Neural Networks(NN), Boosted Decision Trees (BDT) and Matrix element (ME)

Experimental Challenges

Higgs signal is 10 orders of magnitude smaller than background

- Understanding backgrounds
  - SM creates a large variety of background
    - W/Z+jets, dibosons, top, etc. modeled from MC
    - Mistags, QCD modeled from data
  - Critical issues for Higgs
    - Control regions to check bkg. prediction
    - Constrain bkg. prediction $\longrightarrow$ precise measurements of SM cross section
    - Testing tools and techniques: Measurements of bkg. processes such as WW, WZ, single-top, etc.
- Advanced analysis techniques (Neural Networks(NN), Boosted Decision Trees (BDT) and Matrix element (ME)

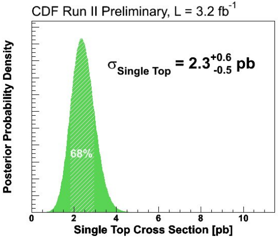


Single-top process has same signature than Higgs, was observed March09 using similar techniques than for Higgs searches. See talk A.Heinson

Experimental Challenges

Higgs signal is 10 orders of magnitude smaller than background

- Understanding backgrounds
  - SM creates a large variety of background
    - W/Z+jets, dibosons, top, etc. modeled from MC
    - Mistags, QCD modeled from data
  - Critical issues for Higgs
    - Control regions to check bkg. prediction
    - Constrain bkg. prediction $\longrightarrow$ precise measurements of SM cross section
    - Testing tools and techniques: Measurements of bkg. processes such as WW, WZ, single-top, etc.
- Advanced analysis techniques (Neural Networks(NN), Boosted Decision Trees (BDT) and Matrix element (ME)



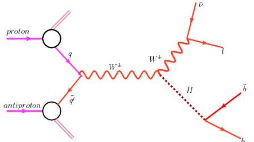
Single-top process has same signature than Higgs, was observed March09 using similar techniques than for Higgs searches. See talk A.Heinson

1. Introduction
   - Tevatron
   - Experiments
   - Higgs Boson in SM

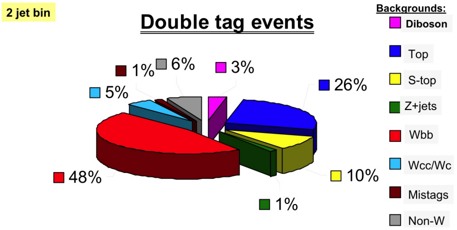
2. Tevatron Results
   - Low Higgs Mass region
     - $WH \longrightarrow l\nu b\bar{b}$
     - $ZH \longrightarrow llb\bar{b}$
     - $VH \longrightarrow b\bar{b}+$ Missing Transverse Energy
   - High Higgs Mass region
     - $H \longrightarrow WW$
   - Other Analysis
   - Combination
     - Individual experiments combination
     - Tevatron combination

3. Conclusions and Perspective

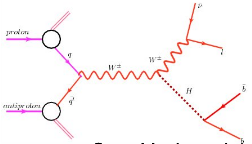
$WH \to l\nu b\bar{b}$: Most sensitive channel at low mass



- Signature: One High isolated P_T lepton, high $\not{E}_T$ and 2 b-jets
- Backgrounds: W+jets, top, Mistags, QCD, Z+jets, ..



$WH \to l\nu b\bar{b}$: Most sensitive channel at low mass

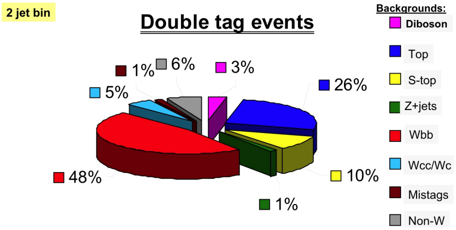


- Signature: One High isolated P_T lepton, high $\not{E}_T$ and 2 b-jets
- Backgrounds: W+jets, top, Mistags, QCD, Z+jets, ..
- Analysis strategy:
  - Split in tagging categories:
    - only 1 good identified b-jet or 2 or more b-jets

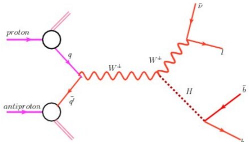
  D0: use NN to separate signal from bkg.

  CDF: have two analyses with NN and BDT → Combined using another NN

  - Use of Matrix Elements Information in the MVA



$WH \to l\nu b\bar{b}$: Most sensitive channel at low mass

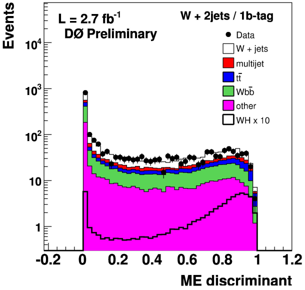


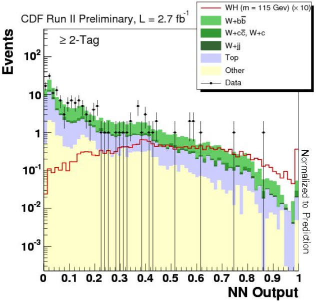
- Signature: One High isolated P_T lepton, high $\not{E}_T$ and 2 b-jets
- Backgrounds: W+jets, top, Mistags, QCD, Z+jets, ..
- Analysis strategy:
  - Split in tagging categories:
    - only 1 good identified b-jet or 2 or more b-jets

D0: use NN to separate signal from bkg.

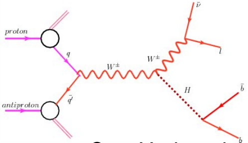
CDF: have two analyses with NN and BDT $\to$ Combined using another NN

- Use of Matrix Elements Information in the MVA





$WH \to l\nu b\bar{b}$: Most sensitive channel at low mass



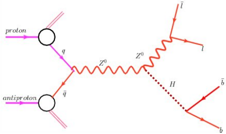
- Signature: One High isolated P_T lepton, high $\not{E}_T$ and 2 *b*-jets
- Backgrounds: W+jets, top, Mistags, QCD, Z+jets, ..
- Analysis strategy:
  - Split in tagging categories:
    - only 1 good identified *b*-jet or 2 or more *b*-jets

  D0: use NN to separate signal from bkg.

  CDF: have two analyses with NN and BDT → Combined using another NN
  - Use of Matrix Elements Information in the MVA

Exp.	Lum	Expected	Observed
	(fb^{-1})	95% C.L. limit/SM	
D0	2.7	6.7	6.4
CDF	2.7	4.8	5.6
$M_H = 115$ *GeV*			

$ZH \rightarrow ll b\bar{b}$: Cleanest signature but low event rate



- Signature: two isolated High P_T leptons, and b-jets
- Backgrounds :Z+jets($\rightarrow b\bar{b}/c\bar{c}$), QCD, dibosons
- Analysis strategy:
  - Extended lepton coverage and requiered M_{ll} window
  - Split sample in tagging categories

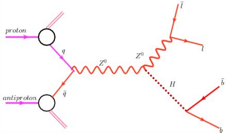
  D0: Split samples also in lepton type

  D0: Use BDT optimized and trained for each sample at each Higgs mass

  CDF: Improve mass resolution correcting jet energies with $\not\!\!E_T$ direction and magnitude

  CDF: Use 2D NN or Matrix Element techniques

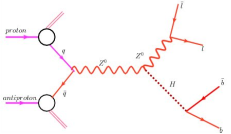
$ZH \rightarrow llb\bar{b}$: Cleanest signature but low event rate



- Signature: two isolated High P_T leptons, and b-jets
- Backgrounds :Z+jets($\rightarrow b\bar{b}/c\bar{c}$), QCD, dibosons
- Analysis strategy:
  - Extended lepton coverage and requiered M_{ll} window
  - Split sample in tagging categories

D0: Split samples also in lepton type
D0: Use BDT optimized and trained for each sample at each Higgs mass
CDF: Improve mass resolution correcting jet energies with $\not\!\!E_T$ direction and magnitude
CDF: Use 2D NN or Matrix Element techniques

$ZH \to llb\bar{b}$: Cleanest signature but low event rate



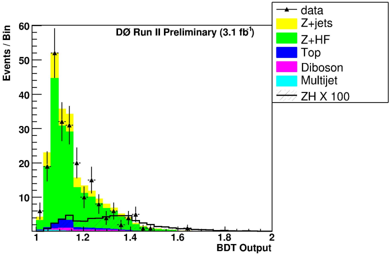
- Signature: two isolated High P_T leptons, and b-jets
- Backgrounds :Z+jets($\to b\bar{b}/c\bar{c}$), QCD, dibosons
- Analysis strategy:
  - Extended lepton coverage and requiered M_{ll} window
  - Split sample in tagging categories

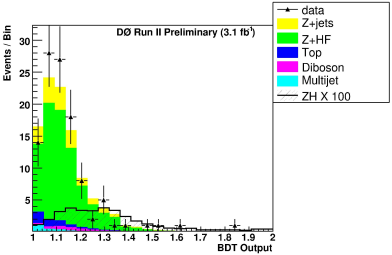
  D0: Split samples also in lepton type

  D0: Use BDT optimized and trained for each sample at each Higgs mass

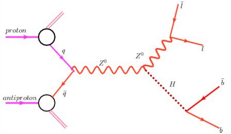
  CDF: Improve mass resolution correcting jet energies with $\not{E}_T$ direction and magnitude

  CDF: Use 2D NN or Matrix Element techniques

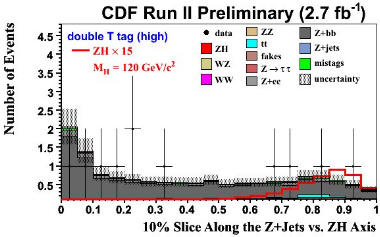


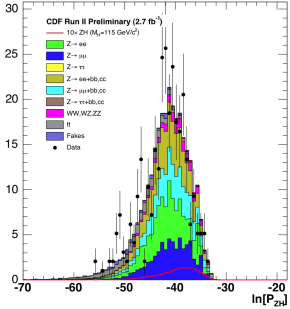


$ZH \rightarrow llb\bar{b}$: Cleanest signature but low event rate

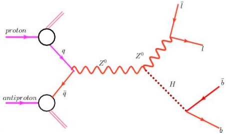


- Signature: two isolated High P_T leptons, and b-jets
- Backgrounds :Z+jets($\rightarrow b\bar{b}/c\bar{c}$), QCD, dibosons
- Analysis strategy:
  - Extended lepton coverage and requiered M_{ll} window
  - Split sample in tagging categories
  - D0: Split samples also in lepton type
  - D0: Use BDT optimized and trained for each sample at each Higgs mass
  - CDF: Improve mass resolution correcting jet energies with $\not\!\!E_T$ direction and magnitude
  - CDF: Use 2D NN or Matrix Element techniques





$ZH \rightarrow llb\bar{b}$: Cleanest signature but low event rate



- Signature: two isolated High P_T leptons, and b-jets
- Backgrounds :Z+jets($\rightarrow b\bar{b}/c\bar{c}$), QCD, dibosons
- Analysis strategy:
  - Extended lepton coverage and requiered M_{ll} window
  - Split sample in tagging categories

D0: Split samples also in lepton type

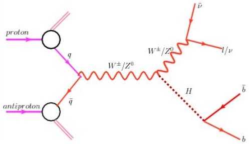
D0: Use BDT optimized and trained for each sample at each Higgs mass

CDF: Improve mass resolution correcting jet energies with $\not{E}_T$ direction and magnitude

CDF: Use 2D NN or Matrix Element techniques

Exp.	Lum (fb^{-1})	Expected 95% C.L. limit/SM	Observed 95% C.L. limit/SM
D0	4.2	8.0	9.1
CDF NN	2.7	9.9	7.1
CDF ME	2.7	12.21	7.8
$M_H = 115\ GeV$			

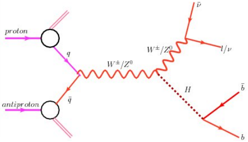
$VH \to \not{E}_T b\bar{b}$: Accept $WH \to$ where lepton is not found (≈ 50% of the signal)



- Signature: large $\not{E}_T$ and b-jets
- Backgrounds: QCD, Z/W+jets, Top and Diboson
- Analysis strategy:
  - Veto events with a lepton
  - Control Regions to model QCD and W+jets bck.

CDF: Remove 70% of QCD bkg. using a NN
CDF: Split events in tagging categories
CDF: Use another NN to separate signal from background
D0: Use two b-tagged jets
D0: Use BDT to separate signal from background

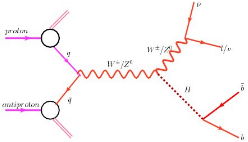
$VH \to \not{E}_T b\bar{b}$: Accept $WH \to$ where lepton is not found (≈ 50% of the signal)



- Signature: large $\not{E}_T$ and b-jets
- Backgrounds: QCD, Z/W+jets, Top and Diboson
- Analysis strategy:
  - Veto events with a lepton
  - Control Regions to model QCD and W+jets bck.

CDF: Remove 70% of QCD bkg. using a NN
CDF: Split events in tagging categories
CDF: Use another NN to separate signal from background
D0: Use two b-tagged jets
D0: Use BDT to separate signal from background

$VH \to \not\!\!E_T b\bar{b}$: Accept $WH \to$ where lepton is not found (≈ 50% of the signal)



- Signature: large $\not\!\!E_T$ and b-jets
- Backgrounds: QCD, Z/W+jets, Top and Diboson
- Analysis strategy:
  - Veto events with a lepton
  - Control Regions to model QCD and W+jets bck.

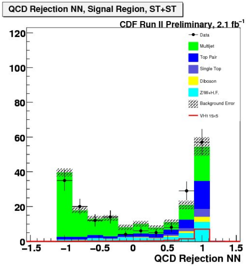
CDF: Remove 70% of QCD bkg. using a NN

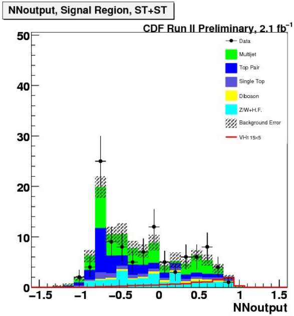
CDF: Split events in tagging categories

CDF: Use another NN to separate signal from background

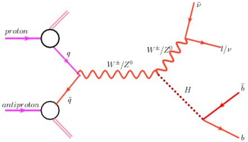
D0: Use two b-tagged jets

D0: Use BDT to separate signal from background





$VH \to \not{E}_T b\bar{b}$: Accept $WH \to$ where lepton is not found (≈ 50% of the signal)



- Signature: large $\not{E}_T$ and b-jets
- Backgrounds: QCD, Z/W+jets, Top and Diboson
- Analysis strategy:
  - Veto events with a lepton
  - Control Regions to model QCD and W+jets bck.

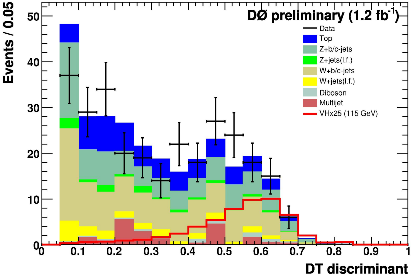
CDF: Remove 70% of QCD bkg. using a NN

CDF: Split events in tagging categories

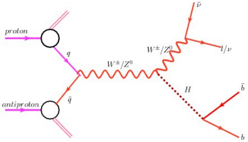
CDF: Use another NN to separate signal from background

D0: Use two b-tagged jets

D0: Use BDT to separate signal from background



$VH \to \not{E}_T b\bar{b}$: Accept $WH \to$ where lepton is not found (≈ 50% of the signal)



- Signature: large $\not{E}_T$ and b-jets
- Backgrounds: QCD, Z/W+jets, Top and Diboson
- Analysis strategy:
  - Veto events with a lepton
  - Control Regions to model QCD and W+jets bck.

CDF: Remove 70% of QCD bkg. using a NN

CDF: Split events in tagging categories

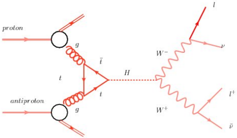
CDF: Use another NN to separate signal from background

D0: Use two b-tagged jets

D0: Use BDT to separate signal from background

Exp.	Lum (fb^{-1})	Expected	Observed
		95% C.L. limit/SM	
D0	2.1	8.4	7.5
CDF	2.1	5.6	6.9
$M_H = 115$ GeV			

$H \to WW$: The most sensitive channel at Tevatron



- Signature: two isolated high P_T leptons and large $\not{E}_T$
- Background: WW, Drell-Yan, top, W plus jets
- Analysis strategy:
  - Use related $\not{E}_T$ variables and M_{ll} cut to reduce DY

CDF: Separate analysis in 0,1,2 jets using NN

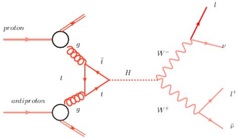
CDF: 0 jets use NN with Matrix Element

CDF: 1,2 jets adds sensitivity from VH and VBF (NN)

D0: Separate lepton channels ee, $\mu\mu$ and eμ

D0: Use NN optimized for each channel

$H \rightarrow WW$: The most sensitive channel at Tevatron



- Signature: two isolated high P_T leptons and large $\not{E}_T$
- Background: WW, Drell-Yan, top, W plus jets
- Analysis strategy:
  - Use related $\not{E}_T$ variables and M_{ll} cut to reduce DY

CDF: Separate analysis in 0,1,2 jets using NN

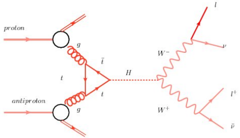
CDF: 0 jets use NN with Matrix Element

CDF: 1,2 jets adds sensitivity from VH and VBF (NN)

D0: Separate lepton channels ee, $\mu\mu$ and eμ

D0: Use NN optimized for each channel

$H \to WW$: The most sensitive channel at Tevatron



- Signature: two isolated high P_T leptons and large $\not{E}_T$
- Background: WW, Drell-Yan, top, W plus jets
- Analysis strategy:
  - Use related $\not{E}_T$ variables and M_{ll} cut to reduce DY

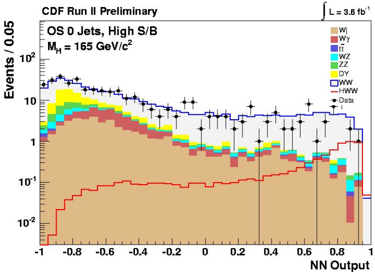
CDF: Separate analysis in 0,1,2 jets using NN

CDF: 0 jets use NN with Matrix Element

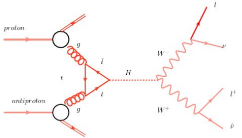
CDF: 1,2 jets adds sensitivity from VH and VBF (NN)

D0: Separate lepton channels ee, $\mu\mu$ and eμ

D0: Use NN optimized for each channel



$H \to WW$: The most sensitive channel at Tevatron



- Signature: two isolated high P_T leptons and large $\not\!\!E_T$
- Background: WW, Drell-Yan, top, W plus jets
- Analysis strategy:
  - Use related $\not\!\!E_T$ variables and M_{ll} cut to reduce DY

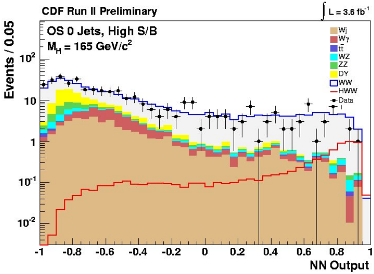
CDF: Separate analysis in 0,1,2 jets using NN

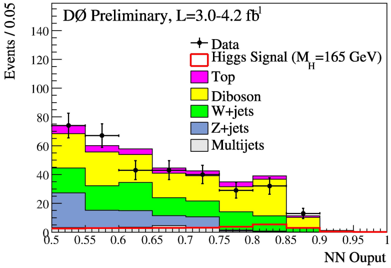
CDF: 0 jets use NN with Matrix Element

CDF: 1,2 jets adds sensitivity from VH and VBF (NN)

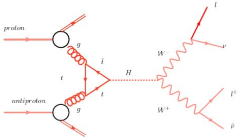
D0: Separate lepton channels ee, $\mu\mu$ and eμ

D0: Use NN optimized for each channel





$H \to WW$: The most sensitive channel at Tevatron



- Signature: two isolated high P_T leptons and large $\not{E}_T$
- Background: WW, Drell-Yan, top, W plus jets
- Analysis strategy:
  - Use related $\not{E}_T$ variables and M_{ll} cut to reduce DY

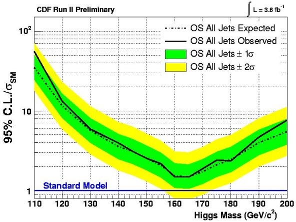
CDF: Separate analysis in 0,1,2 jets using NN

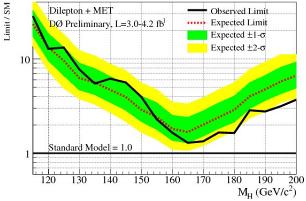
CDF: 0 jets use NN with Matrix Element

CDF: 1,2 jets adds sensitivity from VH and VBF (NN)

D0: Separate lepton channels ee, $\mu\mu$ and eμ

D0: Use NN optimized for each channel





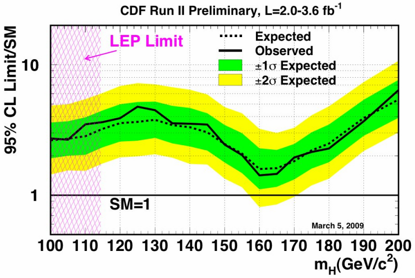
Exp.	Lum	Expected	Observed
	(fb^{-1})	95% C.L. limit/SM	
D0	3.0-4.2	1.8	1.7
CDF	3.6	1.5	1.5
$M_H = 160\ GeV$			

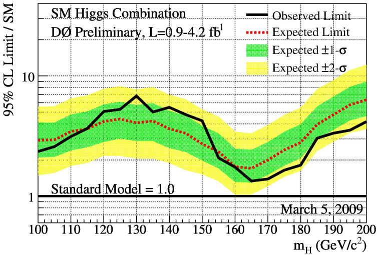
Other analysis : recent results

channel	Analysis Tech.	Lum (fb^{-1})	Expected	Observed
			95% C.L. limit/SM	
CDF experiment				
$VH \to qqb\bar{b}$	NN	2.0	36.8 (M_H=115GeV)	37.5 (M_H=115GeV)
$VH/VBF/gg \to H \to \tau\tau b\bar{b}$	NN	2.0	26.1 (M_H=115GeV)	30.5 (M_H=115GeV)
$WH \to WWW$	NN	3.5	7.22 (M_H=160GeV)	6.60 (M_H=160GeV)
D0 experiment				
$H \to \gamma\gamma$	NN	4.2	18.5 (M_H=115GeV)	15.8 (M_H=115GeV)
$WH \to WWW$	MVA	2.5	10.7 (M_H=160GeV)	18.4 (M_H=160GeV)
$ttH \to t\bar{t}b\bar{b}$	Cut	2.1	45.3 (M_H=115GeV)	63.9 (M_H=115GeV)

There are more ongoing analysis in both experiments which contribute to increase the sentivity but the results have not been updated yet

Experiments Combination





CDF Combination:

Bayesian method to estimate the limit

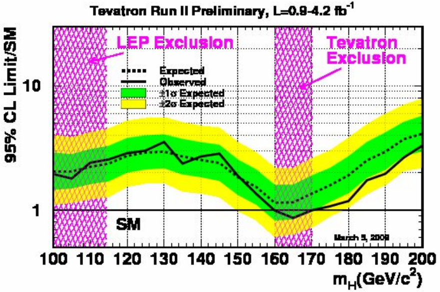
D0 Combination:

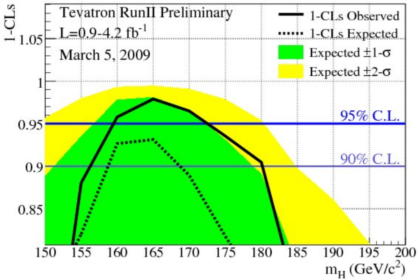
CLs method to estimate the limit

- Both experiments classifying the systematics uncertainties in two main classes
  - Rate syst.: Affects normalization of discriminators
  - Shapes syst.: Small effect on sensitivity. Modify shape of discriminators

Tevatron Combination

- Full set of analysis has been used ($\mathcal{L} = 0.9 - 4.2$ fb^{-1})
- Bayesian and modified frequentist approaches are performed given similar results
  - both methods rely on distribution rather than integrated values
  - both methods use likelihood based on Poisson probabilities
- Latest PDF and $gg \rightarrow H$ theoretical cross section are used
- **Exclude a Higgs Mass Region from 160 to 170 GeV at 95% C.L.**





Conclusions

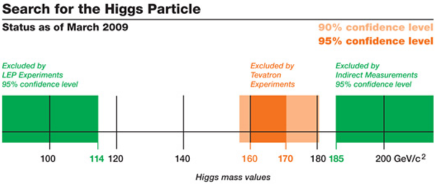
- The Tevatron is performing really well and integrating luminosity faster than ever
- Both Experiments, CDF and D0, have a very active Higgs program with many channels, several analysis techniques.
- Tevatron has excluded a high mass region at 95%C.L. from 160 to 170 GeV
  - Continuous analysis upgrades improve sensitivity
  - Need final push to get sensitivity to all mass ranges
    - More Integrated Luminosity
    - Still room for improvements in new triggers, b-tagging, jet resolution...

Conclusions

- The Tevatron is performing really well and integrating luminosity faster than ever
- Both Experiments, CDF and D0, have a very active Higgs program with many channels, several analysis techniques.
- Tevatron has excluded a high mass region at 95%C.L. from 160 to 170 GeV
  - Continuous analysis upgrades improve sensitivity
  - Need final push to get sensitivity to all mass ranges
    - More Integrated Luminosity
    - Still room for improvements in new triggers, b-tagging, jet resolution ...

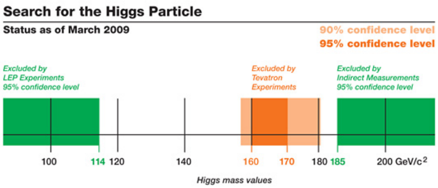
Conclusions

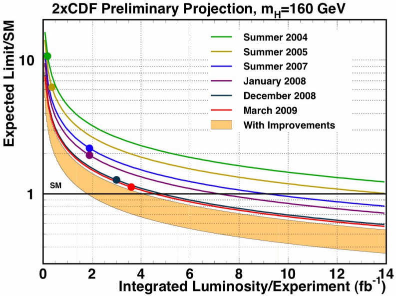
- The Tevatron is performing really well and integrating luminosity faster than ever
- Both Experiments, CDF and D0, have a very active Higgs program with many channels, several analysis techniques.
- Tevatron has excluded a high mass region at 95%C.L. from 160 to 170 GeV
  - Continuous analysis upgrades improve sensitivity
  - Need final push to get sensitivity to all mass ranges
    - More Integrated Luminosity
    - Still room for improvements in new triggers, *b*-tagging, jet resolution...



Conclusions

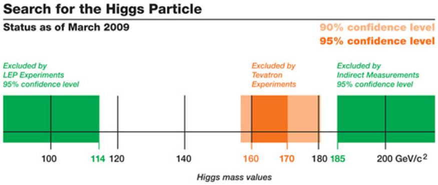
- The Tevatron is performing really well and integrating luminosity faster than ever
- Both Experiments, CDF and D0, have a very active Higgs program with many channels, several analysis techniques.
- Tevatron has excluded a high mass region at 95%C.L. from 160 to 170 GeV
  - Continuous analysis upgrades improve sensitivity
  - Need final push to get sensitivity to all mass ranges
    - More Integrated Luminosity
    - Still room for improvements in new triggers, b-tagging, jet resolution...

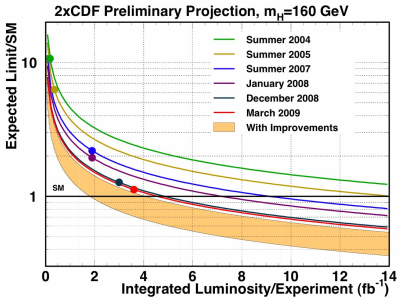




Conclusions

- The Tevatron is performing really well and integrating luminosity faster than ever
- Both Experiments, CDF and D0, have a very active Higgs program with many channels, several analysis techniques.
- Tevatron has excluded a high mass region at 95%C.L. from 160 to 170 GeV
  - Continuous analysis upgrades improve sensitivity
  - Need final push to get sensitivity to all mass ranges
    - More Integrated Luminosity
    - Still room for improvements in new triggers, *b*-tagging, jet resolution...





Stay tune for coming results

Thanks

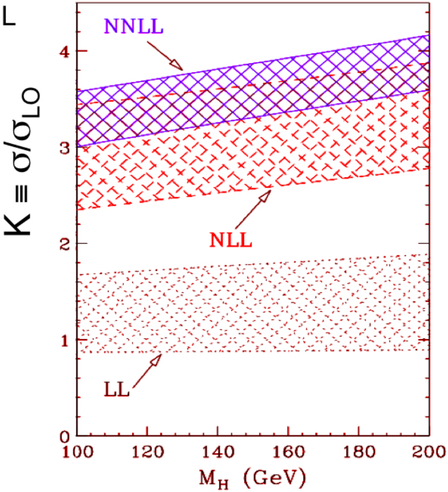
Backup Slides from Tom Junk

Recent $gg \to H$ production cross section progress

- NLO corrections – $\tilde{8}0\%$ (almost double the cross section)
- NNLO QCD corrections – An additional 40% on top of that
- Residual uncertainty $\tilde{1}0\%$. Catani, de Florian, Grazzini, Nason JHEP 0307, 028 (2003) hep-ph/0306211
- Also resummed QCD corrections at NNLL

NLL,NNLL bands: $0.5mH \leq \mu F, \mu R \leq 2MH$. Bands on LO and LL unreliable.

L



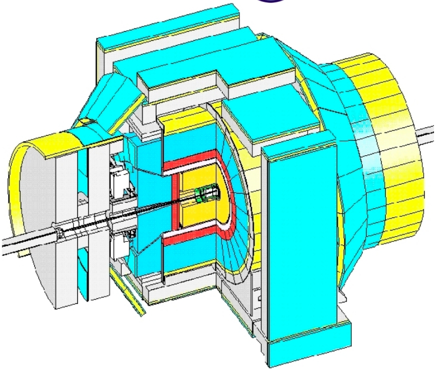
tevatron Performance Constantly improves

A partial list of improvements:

- Store antiprotons in recycler
- Faster transfers from $\bar{p}$ accumulator to recycler
- Electron cooling of pbars in recycler
- Efficiency and reliability of injection
- Faster shot setup
- Separation of orbits at parasitic crossings
- Replacement of 1200 He relief valves
- Faster beam aborts during quenches
- *cogging* pbars to prevent quenches during acceleration

CDF Detector Coverage

The CDF Detector



Lepton coverage:
$|\eta| < 1.5$ (muons)
$|\eta| < 2.0$ (electrons)

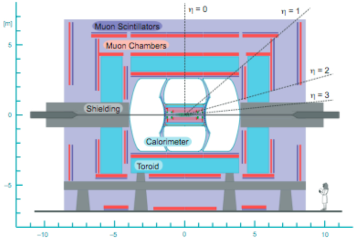
b-tagging with
$|\eta| < \sim 1.4$

Jets to
$|\eta| < 2.8$
Higgs analyses restrict to
$|\eta| < 2.0$

Dijet mass resolution: ~16%

D0 Detector Coverage

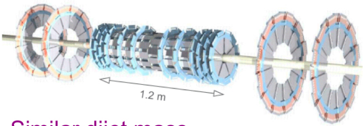
The D0 Detector



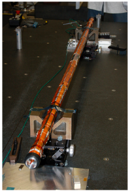
Lepton coverage:
|η| < 2 (muons)
|η| < 2.6 (electrons)

b-tagging with
|η| < ~2

Jets to
|η| < 3

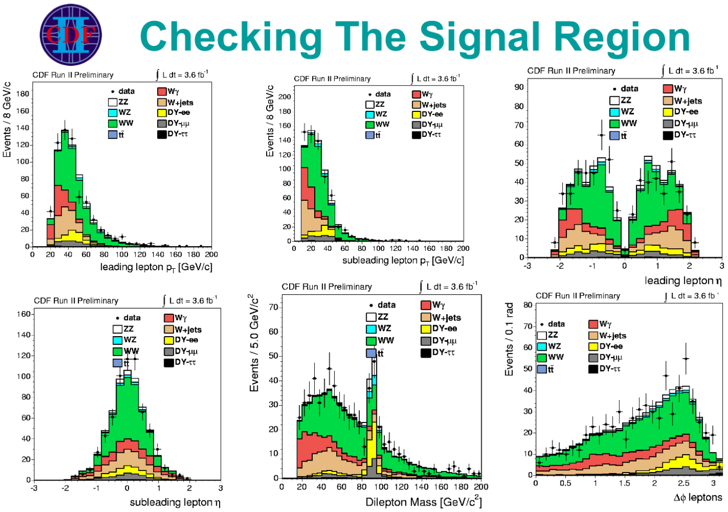


Similar dijet mass resolution to CDF



New Innermost Silicon Layer added between Run IIa and Run IIb

Checking Signal Regions



Steps Required for Combination

- histograms(75 channels, 23 from CDF and 52 from D0) and named rate and shape errors exchanged
- Check stacked histograms and systematic tables with analysis documentation total counts: Data, signal, background
- Repeat individual channel limits $\longrightarrow$ compare against approved results
- Asses correlations on systematics

CDF and D0 teams each do three combinations, using Bayesian and CL_s techniques: CDF, D0 and Tevatron
Consistency at the better than 10% level requiered for all combinaitons at all test masses.
Take the weaker limits

Tevatron Correlated systematics

- Total systematic error count : 109 (not counting bin-by-bin errors)
- Note: correlations in errors on backgorund betwen experiments helps sensitivity One experiment is another exp. control sample
- Luminosity: 3.8% correlated CDF and D0 from $\sigma_{ine\ p\bar{p}}$, 4.4% detector specific
- Diboson Cross sections (6% relative uncertainty)
- $t\bar{t}$ cross section: Moch and Uwer, evaluated at $m_t = 172.4 \pm 1.2$ GeV $\rightarrow \sigma_{t\bar{t}} = 7.79$ pb with a 10% systematic uncertainty.
- Signal Cross sections: VH is 5%, $gg \rightarrow H$ is 12% and VBF is 10%

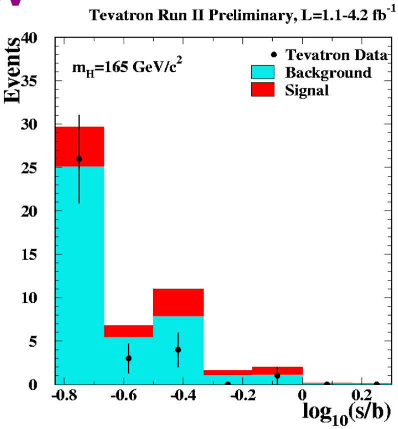
Tevatron Correlated systematics II

- CDF-D0 uncorrelated errors but correlated within the experiments where appropriate:
    - k-factors (data driven)
    - trigger efficiencies
    - b-tag efficiencies and mistags
    - jet energy scale
    - lepton id.fakes and conversions
    - $\not{E}_{\mathrm{T}}$ modeling

A Close-Up in the Highest *s*/*b* bins at m_H=165 GeV

The Last Few Bins' Contents:

Signal yield (events)	Background yield (events)	Data
0.028	0.017	0
0.073	0.060	0
0.918	1.065	1
0.598	0.987	0
3.14	7.84	4
1.38	5.38	3
4.61	25.0	26



Higgs Boson Production Cross Sections and Branching Ratios

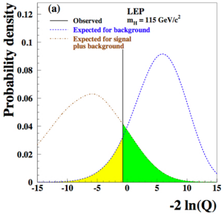
m_H (GeV/c^2)	$\sigma_{gg\to H}$ (fb)	σ_{WH} (fb)	σ_{ZH} (fb)	σ_{VBF} (fb)	$B(H\to b\bar{b})$ (%)	$B(H\to\tau^+\tau^-)$ (%)	$B(H\to W^+W^-)$ (%)
100	1861	286.1	166.7	99.5	81.21	7.924	1.009
105	1618	244.6	144.0	93.3	79.57	7.838	2.216
110	1413	209.2	124.3	87.1	77.02	7.656	4.411
115	1240	178.8	107.4	79.07	73.22	7.340	7.974
120	1093	152.9	92.7	71.65	67.89	6.861	13.20
125	967	132.4	81.1	67.37	60.97	6.210	20.18
130	858	114.7	70.9	62.5	52.71	5.408	28.69
135	764	99.3	62.0	57.65	43.62	4.507	38.28
140	682	86.0	54.2	52.59	34.36	3.574	48.33
145	611	75.3	48.0	49.15	25.56	2.676	58.33
150	548	66.0	42.5	45.67	17.57	1.851	68.17
155	492	57.8	37.6	42.19	10.49	1.112	78.23
160	439	50.7	33.3	38.59	4.00	0.426	90.11
165	389	44.4	29.5	36.09	1.265	0.136	96.10
170	349	38.9	26.1	33.58	0.846	0.091	96.53
175	314	34.6	23.3	31.11	0.663	0.072	95.94
180	283	30.7	20.8	28.57	0.541	0.059	93.45
185	255	27.3	18.6	26.81	0.420	0.046	83.79
190	231	24.3	16.6	24.88	0.342	0.038	77.61
195	210	21.7	15.0	23	0.295	0.033	74.95
200	192	19.3	13.5	21.19	0.260	0.029	73.47

gg→H from Grazzini and de Florian, similar to those of other authors

Tevatron Combined Limits

mass	obs	-2σ	-1σ	exp	$+1\sigma$	$+2\sigma$
100	1.95	1.1	1.45	2.04	2.89	4.02
105	1.79	1.14	1.49	2.04	2.82	3.84
110	2.40	1.22	1.61	2.22	3.09	4.23
115	2.54	1.27	1.70	2.36	3.28	4.48
120	2.86	1.54	1.99	2.72	3.79	5.21
125	3.00	1.64	2.12	2.89	3.99	5.45
130	3.53	1.66	2.16	2.94	4.06	5.55
135	2.36	1.41	1.93	2.69	3.73	5.06
140	2.69	1.36	1.83	2.53	3.51	4.75
145	2.84	1.27	1.71	2.39	3.35	4.57
150	1.88	0.99	1.32	1.83	2.55	3.50
155	1.35	0.83	1.10	1.53	2.12	2.90
160	0.99	0.61	0.82	1.14	1.59	2.18
165	0.86	0.64	0.84	1.15	1.60	2.18
170	0.99	0.72	0.96	1.35	1.89	2.59
175	1.07	0.89	1.16	1.58	2.18	2.99
180	1.18	1.05	1.36	1.90	2.71	3.79
185	1.73	1.35	1.81	2.51	3.52	4.85
190	1.96	1.59	2.10	2.94	4.20	5.92
195	2.64	2.07	2.72	3.72	5.12	6.96
200	3.29	2.19	2.96	4.11	5.72	7.83

Mini-Review: CL_s Limits



p-values:
Yellow area = $1-CL_b = 1-P(-2\ln Q > -2\ln Q_{obs} |$ b only)
Green area = $CL_{s+b} = P(-2\ln Q > -2\ln Q_{obs} |$ s+b)

$CL_s \equiv CL_{s+b}/CL_b \geq CL_{s+b}$
Exclude if $CL_s<0.05$
Vary r until $CL_s=0.05$ to get r_{lim}

- Advantages:
  - Exclusion and Discovery p-values are consistent. Example -- a 2σ upward fluctuation of the data with respect to the background prediciton appears both in the limit and the p-value as such
  - Does not exclude where there is no sensitivity (big enough search region with small enough resolution and you get a 5% dusting of random exclusions with CL_{s+b})

Mini-Review: Bayesian Limits

$$L(r,\theta) = \prod_{channels} \prod_{bins} P_{Poiss}(data \mid r,\theta)$$

Where r is an overall signal scale factor, and θ represents all nuisance parameters.

$$P_{Poiss}(data \mid r,\theta) = \frac{(rs_i(\theta) + b_i(\theta))^{n_i} e^{-(rs_i(\theta)+b_i(\theta))}}{n_i!}$$

where n_i is observed in each bin i, s_i is the predicted signal for a fiducial model (SM), and b_i is the predicted background. Dependence of s_i and b_i on θ includes rate, shape, and bin-by-bin independent uncertainties.

Mini-Review: Bayesian Limits

Including uncertainties on nuisance parameters θ

$$L'(data \mid r) = \int L(data \mid r,\theta)\pi(\theta)d\theta$$

where $\pi(\theta)$ encodes our prior belief in the values of the uncertain parameters. Usually Gaussian centered on the best estimate and with a width given by the systematic. Includes rate uncertainites, shape uncertainites, MC statistics in each bin.

$$0.95 = \int_0^{r_{\text{lim}}} L'(data \mid r)\pi(r)dr$$

Sensitivity = Median Expected Limit

- Run simulated background-only MC pseudoexperiments (fluctuate all systematics)
- Compute r_{lim} for each one; find medain and $\pm 1,2\sigma$ variations.

Contribution	W+HF	Mistags	Top	Diboson	Non-W	WH
Luminosity ($\sigma_{\rm inel}(p\bar{p})$)	0	0	3.8	3.8	0	3.8
Luminosity Monitor	0	0	4.4	4.4	0	4.4
Lepton ID	0	0	2	2	0	2
Jet Energy Scale	0	0	0	0	0	2
Mistag Rate	0	9.0	0	0	0	0
B-Tag Efficiency	0	0	8.4	8.4	0	8.4
$t\bar{t}$ Cross Section	0	0	10	0	0	0
Diboson Rate	0	0	0	11.5	0	0
Signal Cross Section	0	0	0	0	0	5
HF Fraction in W+jets	30.1	0	0	0	0	0
ISR+FSR+PDF	0	0	0	0	0	5.6
QCD Rate	0	0	0	0	40	0

CDF: loose double-tag (LDT) $WH \to \ell\nu b\bar{b}$

Contribution	W+HF	Mistags	Top	Diboson	Non-W	WH
Luminosity ($\sigma_{\rm inel}(p\bar{p})$)	0	0	3.8	3.8	0	3.8
Luminosity Monitor	0	0	4.4	4.4	0	4.4
Lepton ID	0	0	2	2	0	2
Jet Energy Scale	0	0	0	0	0	2
Mistag Rate	0	8.0	0	0	0	0
B-Tag Efficiency	0	0	9.1	9.1	0	9.1
$t\bar{t}$ Cross Section	0	0	10	0	0	0
Diboson Rate	0	0	0	11.5	0	0
Signal Cross Section	0	0	0	0	0	5
HF Fraction in W+jets	30.1	0	0	0	0	0
ISR+FSR+PDF	0	0	0	0	0	4.3
QCD Rate	0	0	0	0	40	0

CDF: single tag (ST) $WH \to \ell\nu b\bar{b}$

Contribution	W+HF	Mistags	Top	Diboson	Non-W	WH
Luminosity ($\sigma_{\rm inel}(p\bar{p})$)	0	0	3.8	3.8	0	3.8
Luminosity Monitor	0	0	4.4	4.4	0	4.4
Lepton ID	0	0	2	2	0	2
Jet Energy Scale	0	0	0	0	0	2
Mistag Rate	0	13.3	0	0	0	0
B-Tag Efficiency	0	0	3.5	3.5	0	3.5
$t\bar{t}$ Cross Section	0	0	10	0	0	0
Diboson Rate	0	0	0	11.5	0	0
Signal Cross Section	0	0	[illegible]	0	0	5
HF Fraction in W+jets	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ISR+FSR+PDF	0	0	0	0	0	3.1
QCD Rate	0	0	0	0	40	0